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Enhanced Component Performance Study: Air-Operated Valves 1998–2016

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ABSTRACT

This report presents an enhanced performance evaluation of air-operated valves (AOVs) at U.S. commercial nuclear power plants. The data used in this study are based on the operating experience failure reports from calendar year 1998 through 2016 as reported in the Institute of Nuclear Power Operations (INPO) Consolidated Events Database (ICES). The AOV failure modes considered are failure-to-open/close, failure to operate or control, and spurious operation. The component reliability estimates and the reliability data are trended for the most recent 10-year period while yearly estimates for reliability are provided for the entire study period. One highly statistically significant increasing trend was observed for the frequency of fail-to-open or close demands per reactor year for low-demand (≤ 20 demands per year) valves.

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ACRONYMS

AFW	auxiliary feed water
AOV	air-operated valve
CCW	component cooling water
CNID	constrained non-informative prior distribution
CRD	control rod drive
CSR	containment spray recirculation
CY	calendar year
EPIX	Equipment Performance and Information Exchange
FTOC	failure-to-open/close
FTOP	failure to operate or control
FY	fiscal year
HCI	high pressure cooling injection
HPI	high pressure injection
ICES	INPO Consolidated Events Database
INPO	Institute of Nuclear Power Operations
ISO	isolation condenser
LCI	low pressure coolant injection
LCS	low pressure core spray
LPI	low pressure injection
MSPI	Mitigating Systems Performance Index
NPRDS	Nuclear Plant Reliability Data System
OLS	ordinary least squares
PRA	probabilistic risk assessment
RCI	reactor core isolation cooling
RCS	reactor coolant system
RHR	residual heat removal
SO	spurious operation
SWN	service water – normally running
SWS	service water – normally in standby

Enhanced Component Performance Study: Air-Operated Valves 1998–2016

1. INTRODUCTION

This report presents a performance evaluation of air-operated valves (AOVs) at U.S. commercial nuclear power plants from 1998 through 2016. The objective of the updated component performance studies is to obtain annual performance trends of failure rates and probabilities and to present an analysis of factors that could influence the component trends. This year's update has two changes from previous year's updates: 1) This year's results are based on calendar year (CY) instead of fiscal year (FY), and 2) The failure events included in this update are now all considered "hard" failures, which is to say the p-values indicating the likelihood the component would have failed during a 24-hour mission are now all 1.0. Previous updates include lesser p-values indicating a degraded condition that probably would have caused failure during a 24-hour mission.

The data used in this study are based on the operating experience failure reports from the Institute of Nuclear Power Operations' (INPO') Consolidated Events Database (ICES) [1], formerly the Equipment Performance and Information Exchange Database (EPIX). Maintenance unavailability (UA) performance data comes from Mitigating Systems Performance Index (MSPI) data from 2002 through 2016 [2]. Data for valves demanded more than 20 times per year (high-demand) are reported separately from the data for lesser-used (low-demand) valves. The AOV failure modes considered are failure-to-open/close (FTOC), failure to operate or control (FTOP), and spurious operation (SO) (see Section 5). Annual failure probabilities (failures per demand) are provided for FTOC events and annual failure rates (failures per valve hour) are provided for FTOP and SO events in Section 3. The estimates are trended for the most recent 10-year period while yearly estimates are provided for the entire study period.

This study is modeled on the web page updates associated with the NUREG-1715 series of reports [3], which were published around 2000. Those studies relied on operating experience obtained from licensee event reports, the Nuclear Plant Reliability Data System (NPRDS), and ICES. The ICES database, which includes MSPI as a subset, has matured to the point where component availability and reliability can be estimated with a higher degree of accuracy. In addition, the population of data in ICES has been growing and is much larger than the population used in the previous study.

While this report provides an overview of operational data and evaluate component performance over time, it makes no attempt to estimate values for use in probabilistic risk assessments (PRAs). The 2015 Component Reliability Update [4], which is an update to NUREG/CR-6928, *Industry-Average Performance for Components and Initiating Events at U.S Commercial Nuclear Power Plants* [5], reports the AOV unreliability estimates for probabilistic risk assessments. Estimates from that report are included herein, for comparisons. These estimates are labelled "2015 Update" (or "Update 2015") in the associated tables and figures.

Engineering analyses were also performed with respect to time period. In Section 4.1, the same failures used in Section 3 are used to estimate overall failure frequencies per plant reactor year. Frequencies of demands per plant reactor year for both groupings of AOVs are also provided for each year. As in Section 3, each of the estimates is trended for the most recent 10-year period. The frequencies show general industry performance and are not based on the number of valves at each plant.

Section 4.2 provides breakdowns of the failures for each failure mode for each valve grouping. The analyses are based on the following factors: sub-component, failure cause, detection method, and recovery.

An overview of the trending methods, glossary of terms, and abbreviations can be found in the Overview and Reference document [6] on the Reactor Operational Experience Results and Databases web page (http://nrcoe.inl.gov/resultsdb).

2. SUMMARY OF FINDINGS

The results of this study are summarized in this section. Of particular interest is the existence of any statistically significant[a] increasing trends.

2.1 Increasing Trends

2.1.1 Extremely Statistically Significant

- None.

2.1.2 Highly Statistically Significant

- Frequency of demands per reactor year for low-demand AOVs FTOC demands (see Figure 7).

2.1.3 Statistically Significant

- None.

2.2 Decreasing Trends

2.2.1 Extremely Statistically Significant

- None

2.2.2 Highly Statistically Significant

- None

2.2.3 Statistically Significant

- None.

a. Statistical significance is defined in terms of the 'p-value.' A p-value is a probability indicating whether to accept or reject the null hypothesis that there is no trend in the data. P-values of less than or equal to 0.05 indicate that we are 95% confident that there is a trend in the data (reject the null hypothesis of no trend.) By convention, we use the "Michelin Guide" scale: p-value < 0.05 (statistically significant), p-value < 0.01 (highly statistically significant); p-value < 0.001 (extremely statistically significant).

3. FAILURE PROBABILITIES AND FAILURE RATES

3.1 Overview

Trends of industry-wide failure probabilities and failure rates for AOVs have been calculated from the operating experience for the FTOC, FTOP, and SO failure modes. The AOV data set obtained from ICES was partitioned to low-demand AOVs (those with less than or equal to 20 demands/year) and high-demand AOVs (those with greater than 20 demands/year). The data set includes AOVs in the systems listed in Table 1.

Table 2 shows industry-wide failure probability and failure rate results for low-demand AOVs from Reference [4], or the 2015 Update. No 2015 Update results are shown for high-demand AOVs because Reference [4] does not provide them. The 2015 Update results are provided for comparison purposes and are important because they are intended for use in PRA. The results in this section demonstrate the extent to which the 2015 Update results remain suitable estimates for use in PRA.

The AOVs are assumed to operate both when the reactor is critical and during shutdown periods. The number of AOVs in operation is the number that have been in operation at some time during the study period. So new devices put in service during the period are included, as are devices that were in service at one time but have since been removed from service. All demand types are considered—testing, non-testing, and, as applicable, engineered safety feature demands.

Table 1. Summary of AOV counts in the systems in which they are found.

System	Description	AOV Count		
		Total	Low Demand	High Demand
AFW	Auxiliary feedwater	389	195	194
CCW	Component cooling water	464	302	162
CRD	Control rod drive	122	67	55
CSR	Containment spray recirculation	38	31	7
HCI	High pressure coolant injection	15	7	8
HPI	High pressure injection	104	74	30
ISO	Isolation condenser	10	6	4
LCS	Low pressure core spray	12	10	2
RCI	Reactor core isolation	5	5	
RCS	Reactor coolant	117	47	70
RHR	Residual Heat Removal (LCI in BWRs; LPI in PWRs)	293	138	155
SWN	Normally operating service water	550	302	248
SWS	Standby service water	63	17	46
	Total	2182	1201	981

Table 2. 2015 Update industry-wide distributions of p (failure probability) and λ (hourly rate) for low-demand AOVs.

Failure Mode	5%	Median	Mean	95%	Distribution		
					Type	α	β
FTOC	3.89E-5	5.25E-4	7.56E-4	2.27E-3	Beta	1.00	1.32E+03
FTOP	2.39E-8	1.76E-7	2.27E-7	6.03E-7	Gamma	1.41	6.22E+06
SO	5.76E-9	7.18E-8	1.02E-7	3.01E-7	Gamma	1.04	1.02E+07

3.2 AOV Failure Probability and Failure Rate Trends

Trends in failure probabilities and failure rates are shown in Figures 1–6. The data for the trend plots are contained in Tables 10–15, respectively.

The failure probability and failure rate estimates in the plots were obtained from a Bayesian update process. The means from the posterior distributions were plotted for each year. The 5th and 95th percentiles from the posterior distributions are also provided and give an indication of the relative uncertainty in the estimated parameters from year to year. When there are no failures, the interval is larger than the interval for years when there are one or more failures. The larger interval reflects the uncertainty that comes from having little information in that year's data. Such uncertainty intervals are determined by the prior distribution. In each plot, in each year, a relatively "flat" constrained non-informative prior distribution (CNID) is used, which has large bounds [7]. For failure probabilities, the posterior means for each year are calculated from

$$mean = \frac{failures + 0.5}{demands + 1} \quad (1)$$

For failure rates, the posterior means for each year are calculated from

$$mean = \frac{failures + 0.5}{operting\ hours} \quad (2)$$

The horizontal curves plotted around the regression lines in the graphs form 90 percent simultaneous confidence bands for the fitted lines. The bounds are larger than ordinary confidence bands for the trended values because they form a band that has a 90% probability of containing the entire line. In the lower left hand corner of the trend figures, the regression p-values are reported. They come from a statistical test on whether the slope of the regression line might be zero. Low p-values indicate that the slopes are not likely to be zero and that trends exist. P-values of less than or equal to 0.05 indicate that we are 95% confident that there is a trend in the data (reject the null hypothesis of no trend.) By convention, this study uses the "Michelin Guide" scale: p-value < 0.05 (statistically significant), p-value < 0.01 (highly statistically significant); p-value < 0.001 (extremely statistically significant).

The regression methods are all based on "ordinary least squares" (OLS); which minimizes the square of the vertical distance between the annual data points and the regression line. The p-values assume normal distributions for the data in each year, with a constant variance across the years. In the case where the data involve failure counts, the method of iterative reweighing accounts for the fact that count data are not expected to have a constant variance (for example, the variance for Poisson-distributed counts is equal to the expected number of counts). Further information on the trending methods is provided in Section 2 of the Overview and Reference document [6].

A final feature of the trend graphs is that the 2015 Update baseline industry values from Table 2 are shown for comparison.

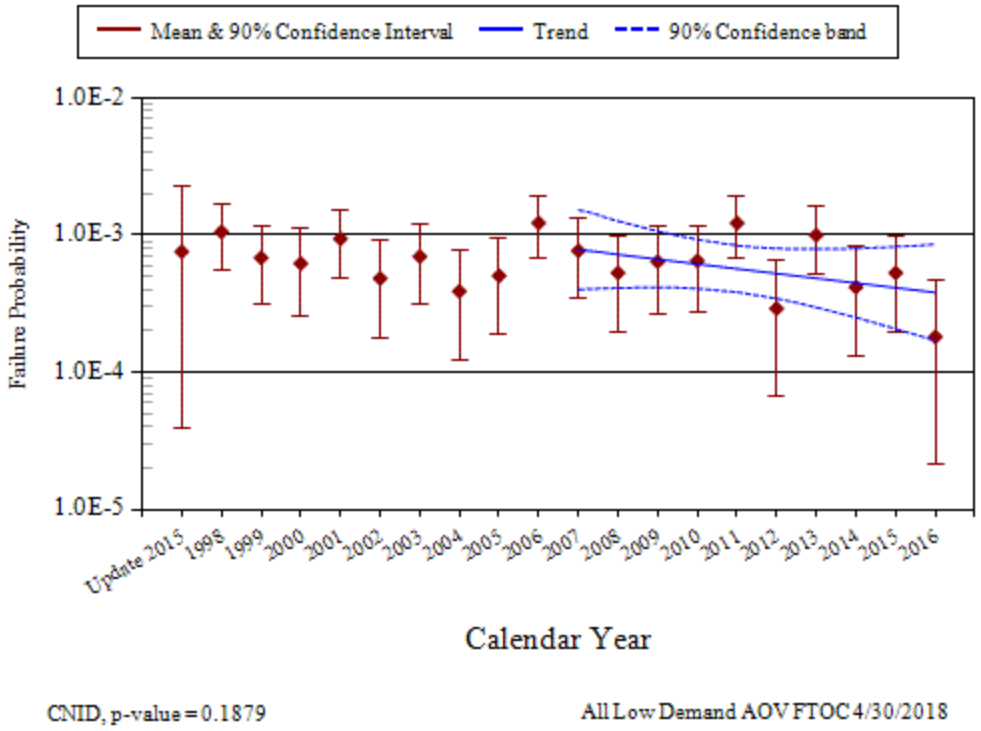

Figure 1. Failure probability estimate trend for all systems, industry-wide, low-demand AOV FTOC.

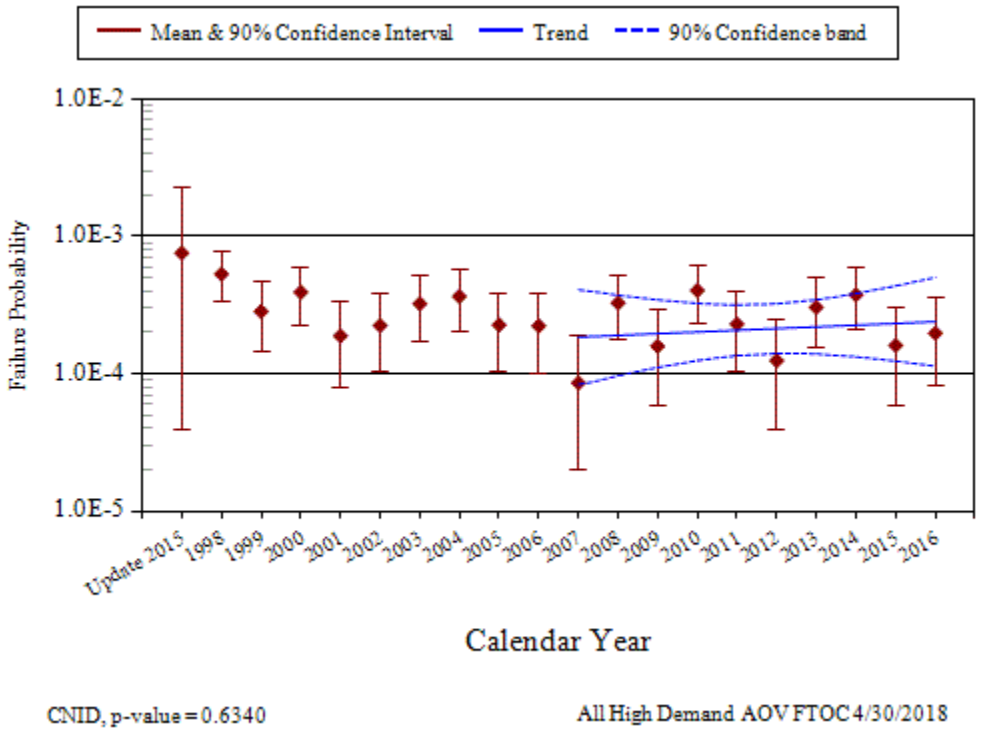

Figure 2. Failure probability estimate trend for all systems, industry-wide, high-demand AOV FTOC.

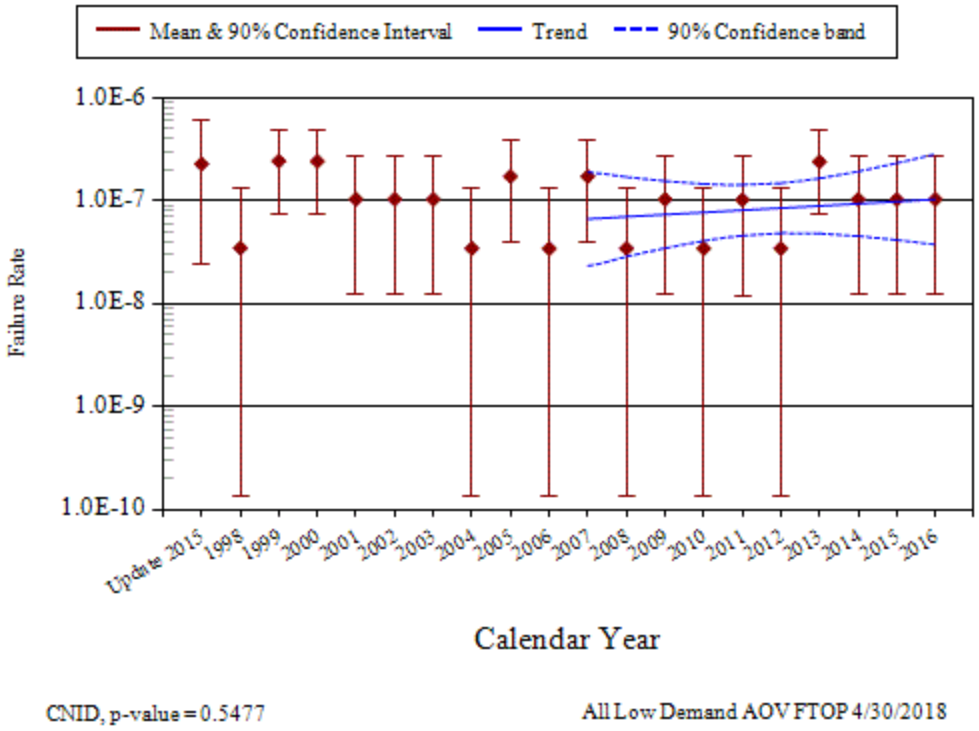

Figure 3. Failure rate estimate trend for all systems, industry-wide, low-demand AOV FTOP.

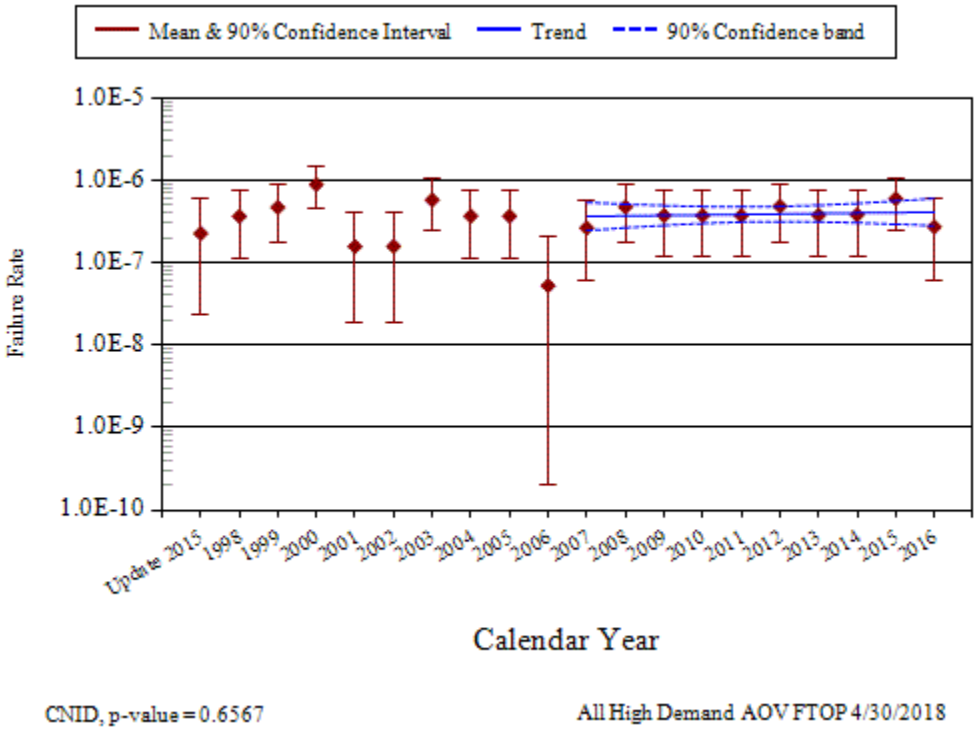

Figure 4. Failure rate estimate trend for all systems, industry-wide, high-demand AOV FTOP.

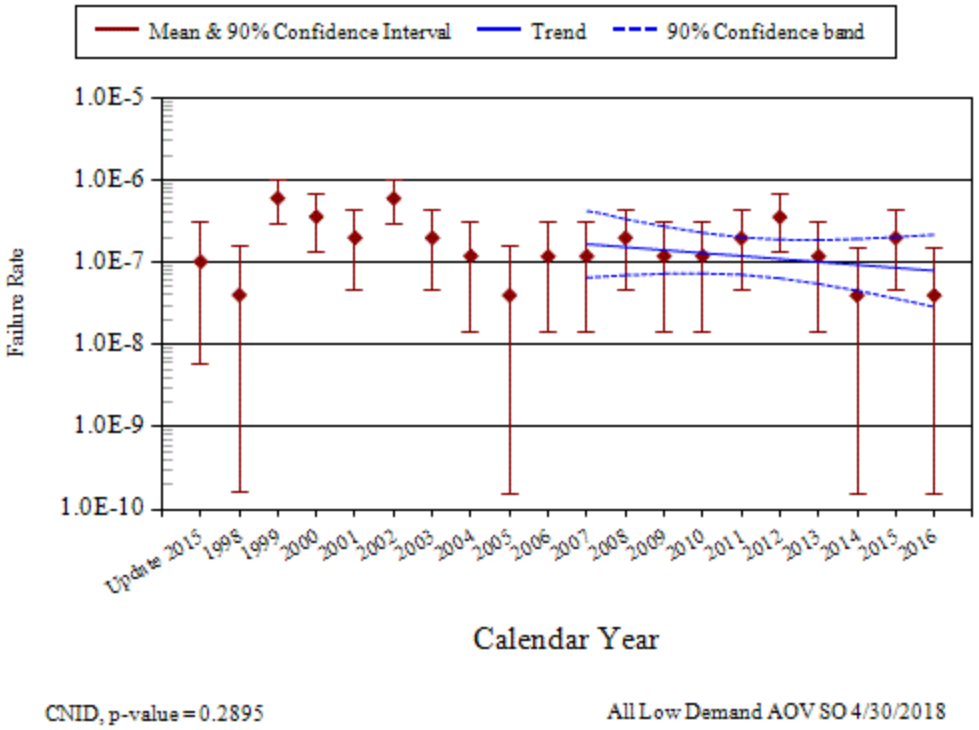

Figure 5. Failure rate estimate trend for all systems, industry-wide, low-demand AOV SO.

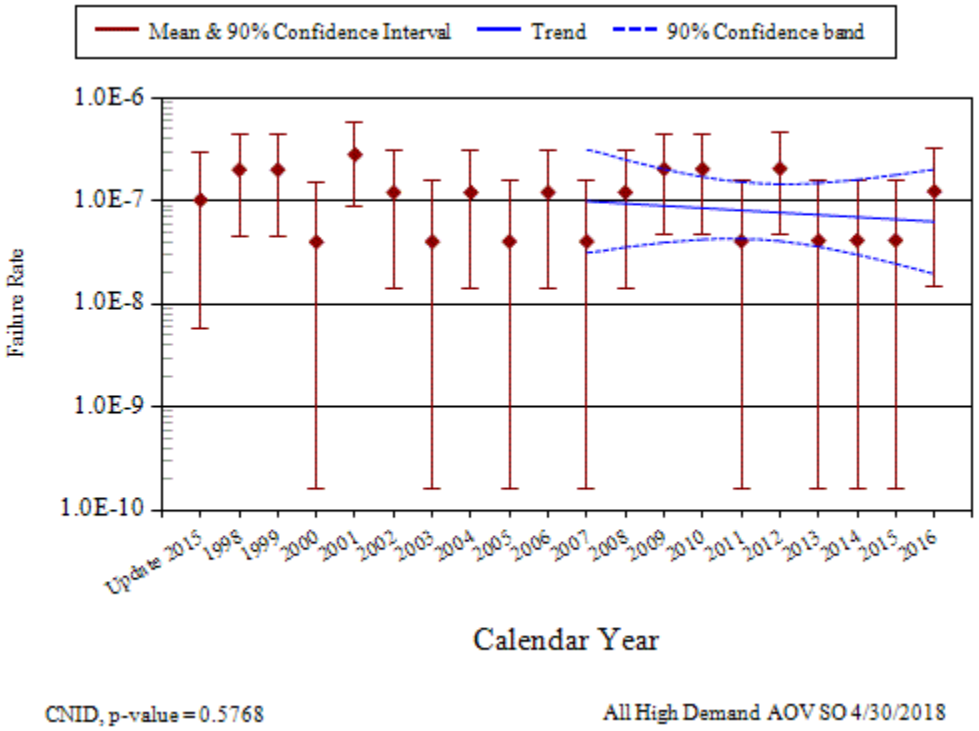

Figure 6. Failure rate estimate trend for all systems, industry-wide, high-demand AOV SO.

4. ENGINEERING ANALYSIS

4.1 Engineering Trends

This section presents frequency trends for AOV failures and demands. The data are normalized by reactor year for plants that report data for the equipment being trended. The trends provide an overview of the demand counts and failure counts associated with each failure mode across the years. Figure 7 shows the trend for total industry AOV demands among low-demand AOVs. Figure 9 shows the trend in failure events for the FTOC mode for low-demand AOVs, Figure 11 shows the trend in failure events for the FTOP mode for these AOVs, and Figure 13 shows the trend for SO failure events for these AOVs.

Figure 8 shows the trend for total AOV demands among high-demand AOVs. Figure 10 shows the trend in failure events for the FTOC mode for high-demand AOVs, Figure 12 shows the trend in failure events for the FTOP mode for these AOVs, and Figure 14 shows the trend for SO failure events for these AOVs.

Table 3 summarizes the FTOC failure counts by system and year for low-demand AOVs. Table 4 summarizes the FTOP failure counts by system and year for low-demand AOVs. Table 5 summarizes the SO failure counts by system and year for low-demand AOVs.

Table 6 summarizes the FTOC failure counts by system and year for high-demand AOVs. Table 7 summarizes the FTOP failure counts by system and year for high-demand AOVs. Table 8 summarizes the SO failure counts by system and year for high-demand AOVs.

Tables 16–23 provide the plot data for frequency (per reactor year) of AOV demands, run hours, FTOC events, FTOP events, and SO events, respectively. The systems from Table 2 are trended together for each figure. The rate methods described in Section 2 of the Overview and Reference document [6] are used.

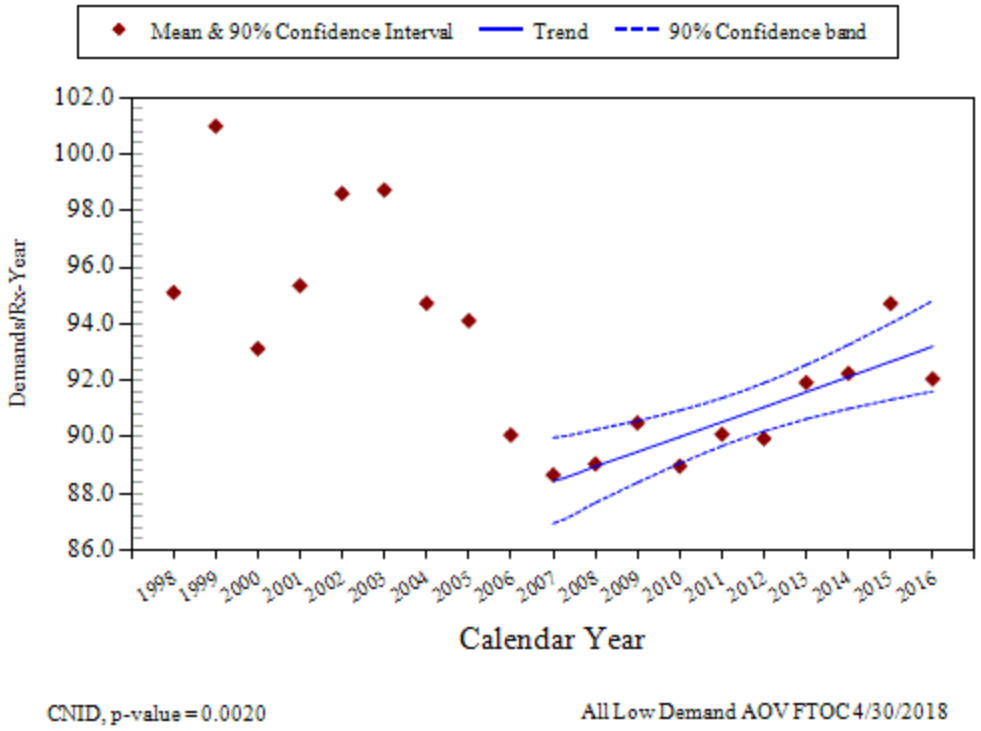

Figure 7. Frequency (demands per reactor year) of low-demand AOV FTOC demands.

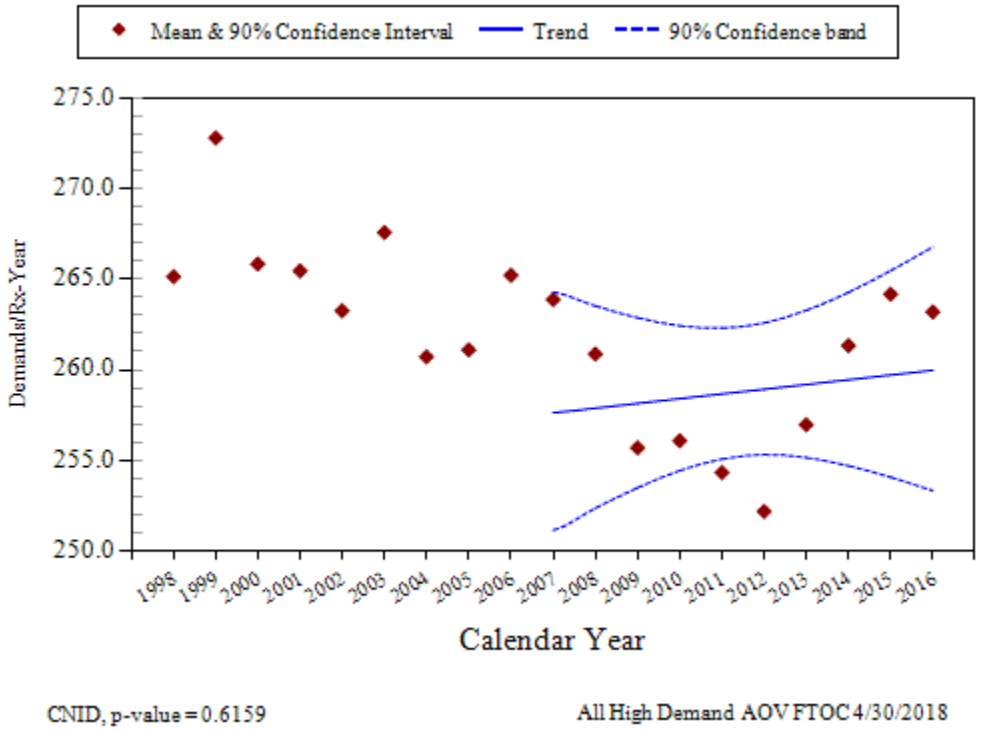

Figure 8. Frequency (demands per reactor year) of high-demand AOV FTOC demands.

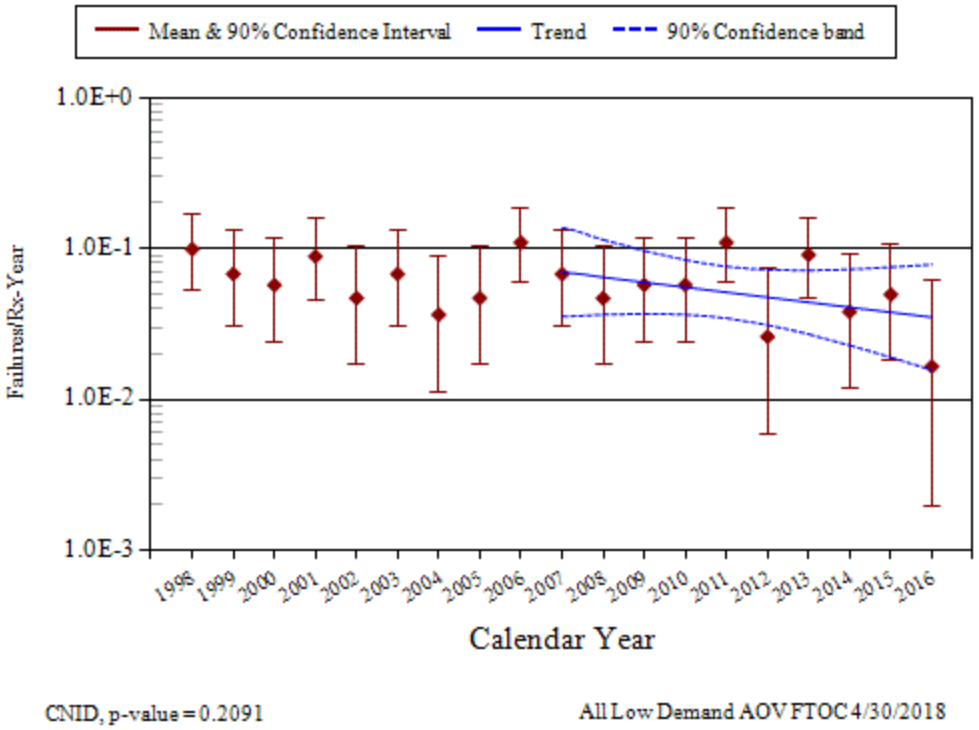

Figure 9. Frequency (failures per reactor year) of low-demand AOV FTOC events.

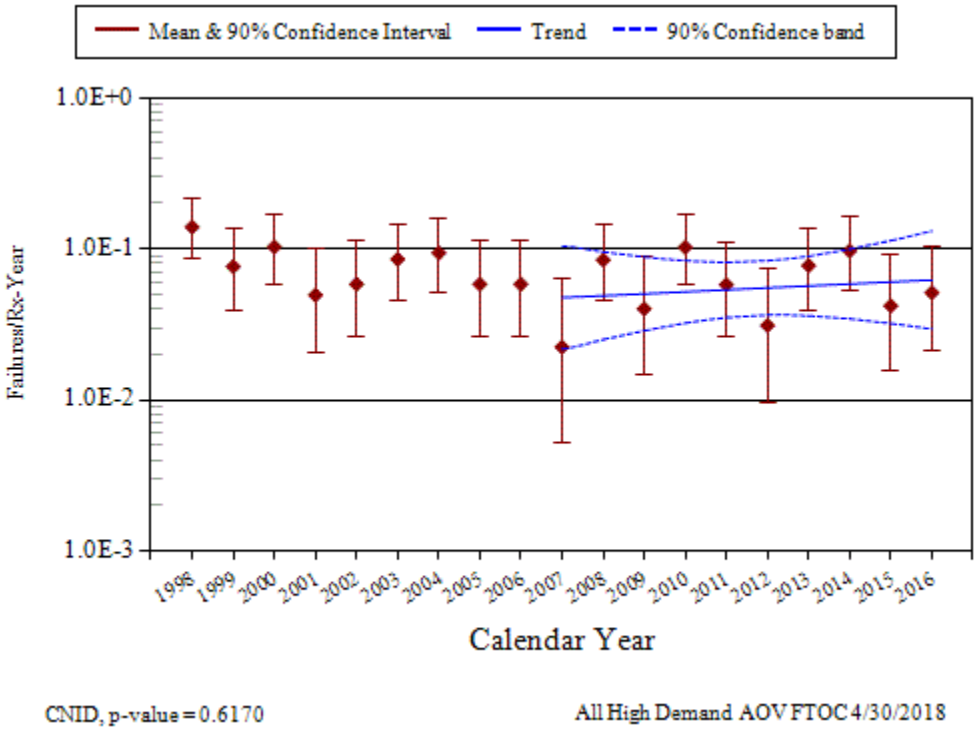

Figure 10. Frequency (failures per reactor year) of high-demand AOV FTOC events.

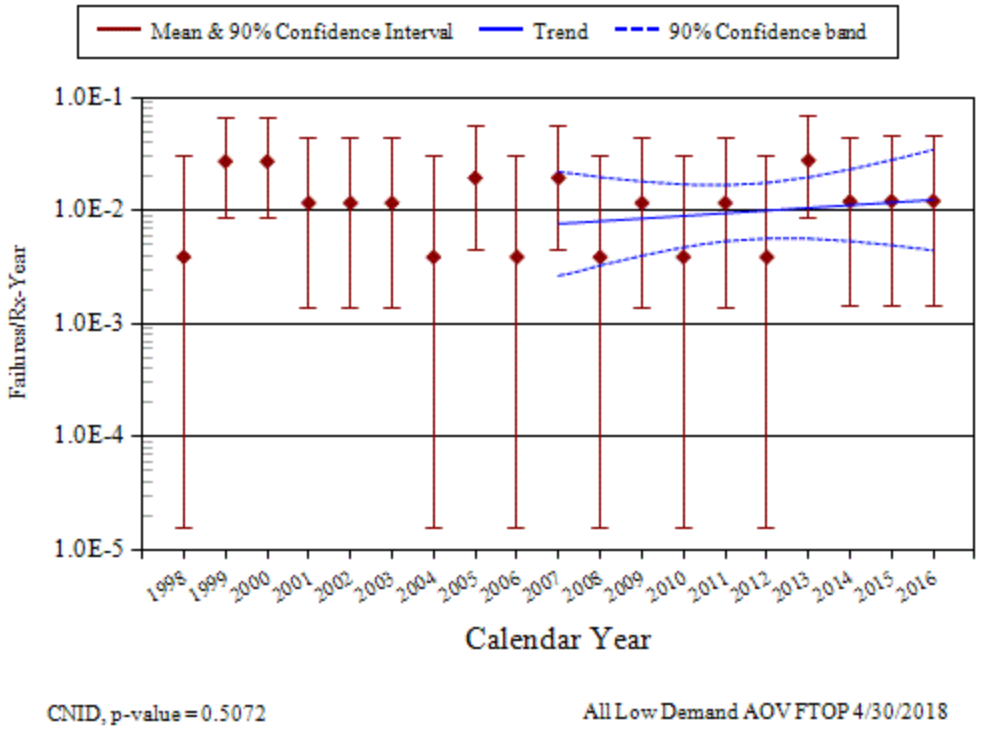

Figure 11. Frequency (failures per reactor year) of low-demand AOV FTOP events.

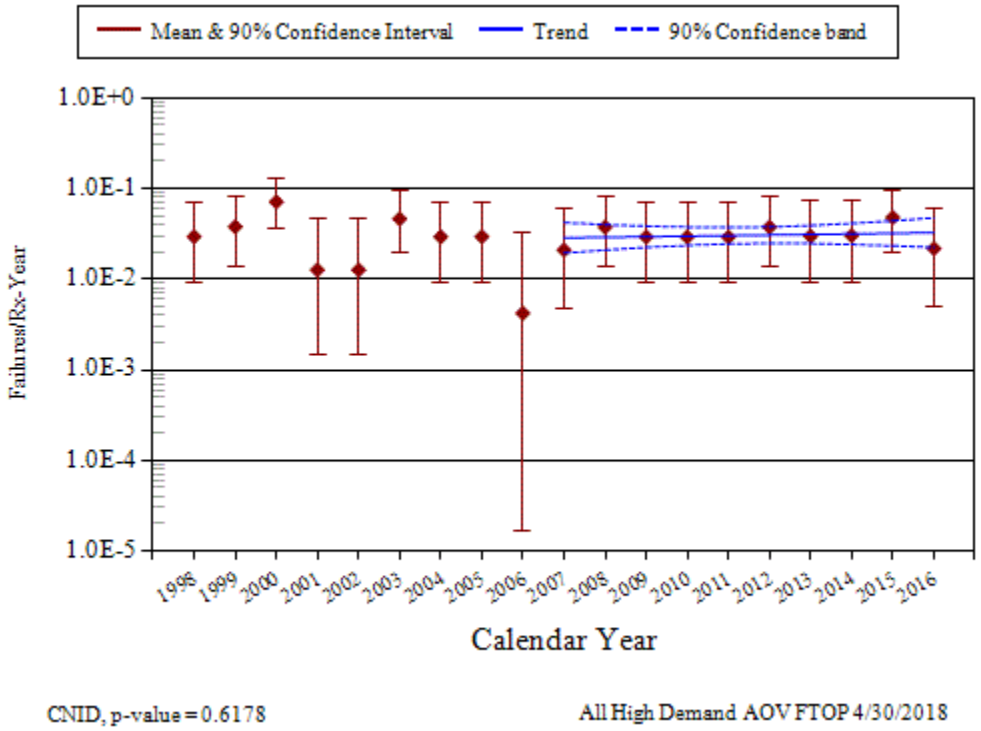

Figure 12. Frequency (failures per reactor year) of high-demand AOV FTOP events.

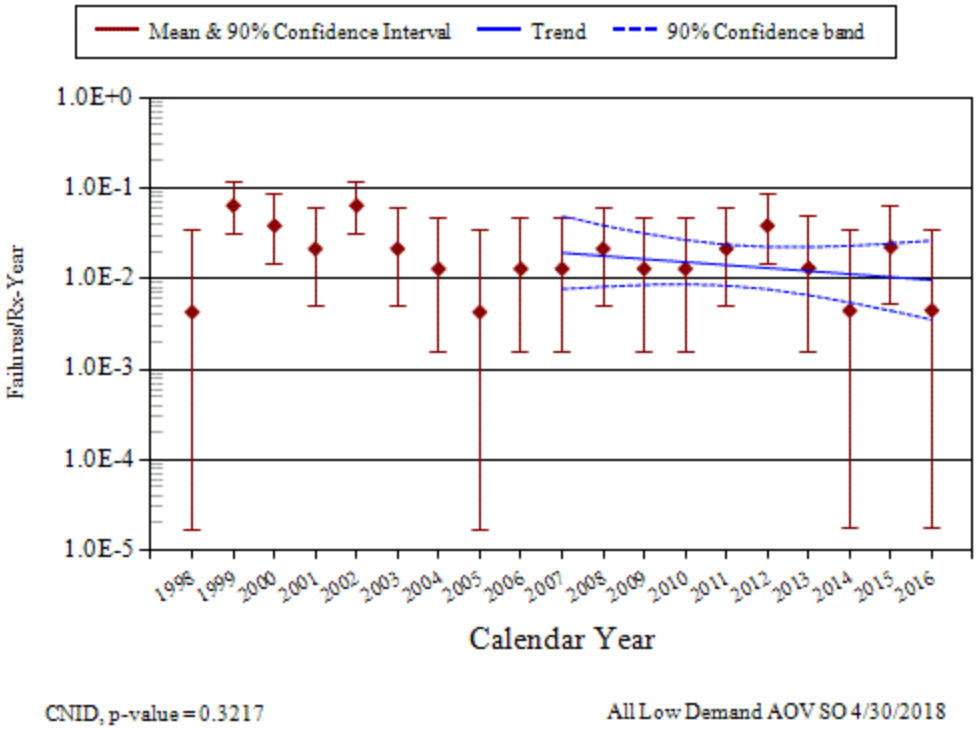

Figure 13. Frequency (failures per reactor year) of low-demand AOV SO events.

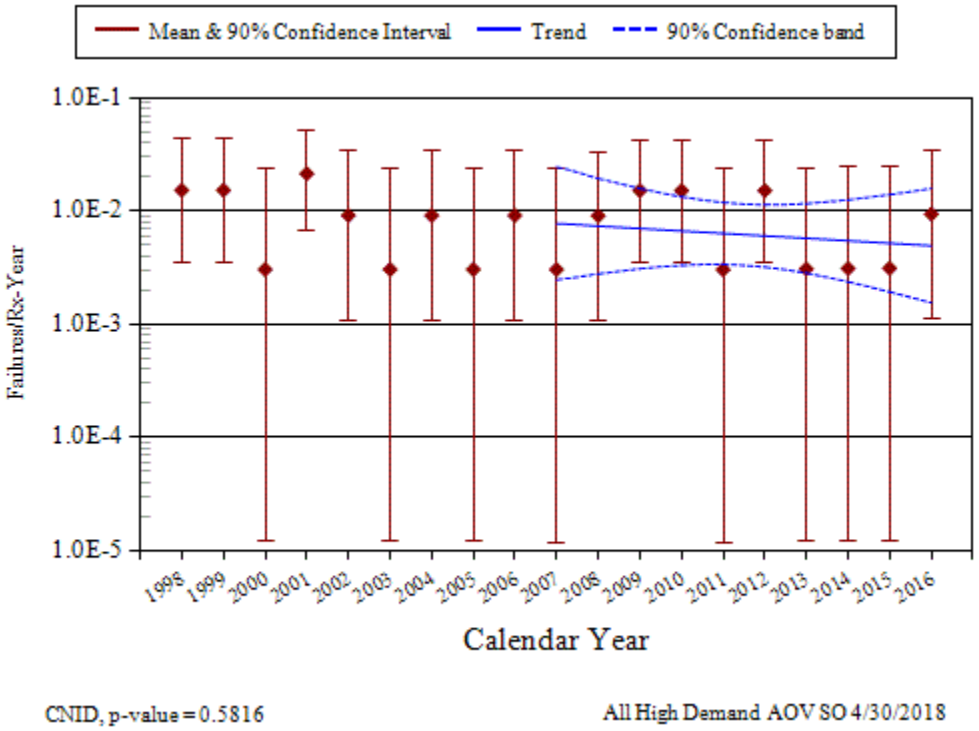

Figure 14. Frequency (failures per reactor year) of high-demand AOV SO events.

Table 3. Summary of low-demand AOV failure counts for the FTOC failure mode over time by system.

System Code	Valve Count	Valve Percent	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total	Percent of Failures
AFW	195	16.2%			1	1		1			2		5	10.4%
CCW	302	25.1%	3			2	2		6	2	2		17	35.4%
CRD	67	5.6%											0	0.0%
CSR	31	2.6%											0	0.0%
HCI	7	0.6%											0	0.0%
HPI	74	6.2%		1			3			1			5	10.4%
ISO	6	0.5%											0	0.0%
LCS	10	0.8%											0	0.0%
RCI	5	0.4%	1										1	2.1%
RCS	47	3.9%			1		1						2	4.2%
RHR	138	11.5%	1	1	1								3	6.3%
SWN	302	25.1%	1	2	2	2	3	1	2			1	14	29.2%
SWS	17	1.4%					1						1	2.1%
Total	1201	100%	6	4	5	5	10	2	8	3	4	1	48	100%

Table 4. Summary of low-demand AOV failure counts for the FTOP failure mode over time by system.

System Code	Valve Count	Valve Percent	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total	Percent of Failures
AFW	195	16.2%							3			1	4	40.0%
CCW	302	25.1%	1		1						1		3	30.0%
CRD	67	5.6%											0	0.0%
CSR	31	2.6%											0	0.0%
HCI	7	0.6%											0	0.0%
HPI	74	6.2%											0	0.0%
ISO	6	0.5%											0	0.0%
LCS	10	0.8%											0	0.0%
RCI	5	0.4%											0	0.0%
RCS	47	3.9%											0	0.0%
RHR	138	11.5%											0	0.0%
SWN	302	25.1%	1							1			2	20.0%
SWS	17	1.4%					1						1	10.0%
Total	1201	100%	2	0	1	0	1	0	3	1	1	1	10	100%

Table 5. Summary of low-demand AOV failure counts for the SO failure mode over time by system.

System Code	Valve Count	Valve Percent	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total	Percent of Failures
AFW	195	16.2%	1	1	1						2		5	35.7%
CCW	302	25.1%				1	1	3					5	35.7%
CRD	67	5.6%											0	0.0%
CSR	31	2.6%											0	0.0%
HCI	7	0.6%											0	0.0%
HPI	74	6.2%											0	0.0%
ISO	6	0.5%											0	0.0%
LCS	10	0.8%											0	0.0%
RCI	5	0.4%											0	0.0%
RCS	47	3.9%											0	0.0%
RHR	138	11.5%		1				1					2	14.3%
SWN	302	25.1%							1				1	7.1%
SWS	17	1.4%					1						1	7.1%
Total	1201	100%	1	2	1	1	2	4	1	0	2	0	14	100%

Table 6. Summary of high-demand AOV failure counts for the FTOC failure mode over time by system.

System Code	Valve Count	Valve Percent	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total	Percent of Failures
AFW	194	19.8%		3		2	1	1	3	5	1		16	25.8%
CCW	162	16.5%				1		1	1				3	4.8%
CRD	55	5.6%						1	1				2	3.2%
CSR	7	0.7%											0	0.0%
HCI	8	0.8%											0	0.0%
HPI	30	3.1%											0	0.0%
ISO	4	0.4%											0	0.0%
LCS	2	0.2%											0	0.0%
RCS	70	7.1%	1			3						1	5	8.1%
RHR	155	15.8%	1		3	1	2		1	1	1	1	11	17.7%
SWN	248	25.3%		6	1	2	3		2	4	2	3	23	37.1%
SWS	46	4.7%				2							2	3.2%
Total	981	100%	2	9	4	11	6	3	8	10	4	5	62	100%

Table 7. Summary of high-demand AOV failure counts for the FTOP failure mode over time by system.

System Code	Valve Count	Valve Percent	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total	Percent of Failures
AFW	194	19.8%	1			1	1	1	2		4		10	31.3%
CCW	162	16.5%		1					1			1	3	9.4%
CRD	55	5.6%						1					1	3.1%
CSR	7	0.7%											0	0.0%
HCI	8	0.8%											0	0.0%
HPI	30	3.1%											0	0.0%
ISO	4	0.4%											0	0.0%
LCS	2	0.2%											0	0.0%
RCS	70	7.1%										1	1	3.1%
RHR	155	15.8%		1				2		1	1		5	15.6%
SWN	248	25.3%	1	2	3	2	2			2			12	37.5%
SWS	46	4.7%											0	0.0%
Total	981	100%	2	4	3	3	3	4	3	3	5	2	32	100%

Table 8. Summary of high-demand AOV failure counts for the SO failure mode over time by system.

System Code	Valve Count	Valve Percent	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Total	Percent of Failures
AFW	194	19.8%				2		1					3	37.5%
CCW	162	16.5%						1				1	2	25.0%
CRD	55	5.6%											0	0.0%
CSR	7	0.7%											0	0.0%
HCI	8	0.8%											0	0.0%
HPI	30	3.1%											0	0.0%
ISO	4	0.4%											0	0.0%
LCS	2	0.2%											0	0.0%
RCS	70	7.1%											0	0.0%
RHR	155	15.8%		1									1	12.5%
SWN	248	25.3%			2								2	25.0%
SWS	46	4.7%											0	0.0%
Total	981	100%	0	1	2	2	0	2	0	0	0	1	8	100%

4.2 AOV Engineering Analysis by Failure Modes

The engineering analysis of AOV failure sub-components, causes, detection methods, and recoverability are presented in this section. Each analysis first divides the events into two categories: low-demand AOVs (with less than or equal to 20 demands/year) and high-demand AOVs (with greater than 20 demands/year).

The second division of the events is by the failure mode determined after ICES data review by the staff. See Section 5 for more description of failure modes.

AOV sub-component contributions to the three failure modes are presented in Figure 15. The sub-component categories are similar to those used in the CCF database. For all three failure modes, the actuator is the largest contributor to the failure rates/probabilities.

AOV cause group contributions to the three failure modes are presented in Figure 16. The cause groups are similar to those used in the CCF database. Table 9 shows the breakdown of the cause groups with the specific causes that were coded during the data collection. The most likely cause for the FTOC and FTOP failure modes is grouped as Internal. Internal means that the cause was related to something within the AOV component such as a worn out part or the normal internal environment. The second most likely cause for the FTOC and FTOP failure mode is grouped as Human or Design. The Human cause group is primarily influenced by maintenance and operating procedures and practices. The Design cause group is influenced by manufacturing, installation, and design issues. The most likely cause for the SO failure mode is Human, closely followed by Internal and Design.

AOV detection methods for the three failure modes are presented in Figure 17. Note that there are differences between the low-demand and high-demand detection methods.

Low-Demand—the most likely detection method for FTOC is a testing demand. The most likely detection method for FTOP and SO is an actual demand.

High-Demand—the most likely detection method for FTOC is an actual demand followed by testing demand. The most likely detection method for FTOP and SO is an actual demand.

AOV failure recoverability determination for three failure modes is presented in Figure 18. The overall non-recovery to recovery ratio is approximately 7:1.

Table 9. Component failure cause groups.

Group	Specific Cause	Description
Design	Construction/installation error or inadequacy	Used when a construction or installation error is made during the original or modification installation. This includes specification of incorrect component or material.
	Design error or inadequacy	Used when a design error is made.
	Manufacturing error or inadequacy	Used when a manufacturing error is made during component manufacture.
External	State of other component	Used when the cause of a failure is the result of a component state that is not associated with the component that failed. An example would be the diesel failed due to no fuel in the fuel storage tanks.
	Ambient environmental stress	Used when the cause of a failure is the result of an environmental condition from the location of the component.
Human	Accidental action (unintentional or undesired human errors)	Used when a human error (during the performance of an activity) results in an unintentional or undesired action.
	Human action procedure	Used when the correct procedure is not followed or the wrong procedure is followed. For example: when a missed step or incorrect step in a surveillance procedure results in a component failure.
	Inadequate maintenance	Used when a human error (during the performance of maintenance) results in an unintentional or undesired action.
Internal	Internal to component, piece-part	Used when the cause of a failure is a non-specific result of a failure internal to the component that failed other than aging or wear.
	Internal environment	The internal environment led to the failure. Debris/Foreign material as well as an operating medium chemistry issue.
	Setpoint drift	Used when the cause of a failure is the result of setpoint drift or adjustment.
	Age/Wear	Used when the cause of the failure is a non-specific aging or wear issue.
Other	Unknown	Used when the cause of the failure is not known.
	Other (stated cause does not fit other categories)	Used when the cause of a failure is provided but it does not meet any one of the descriptions.
Procedure	Inadequate procedure	Used when the cause of a failure is the result of an inadequate procedure operating or maintenance.

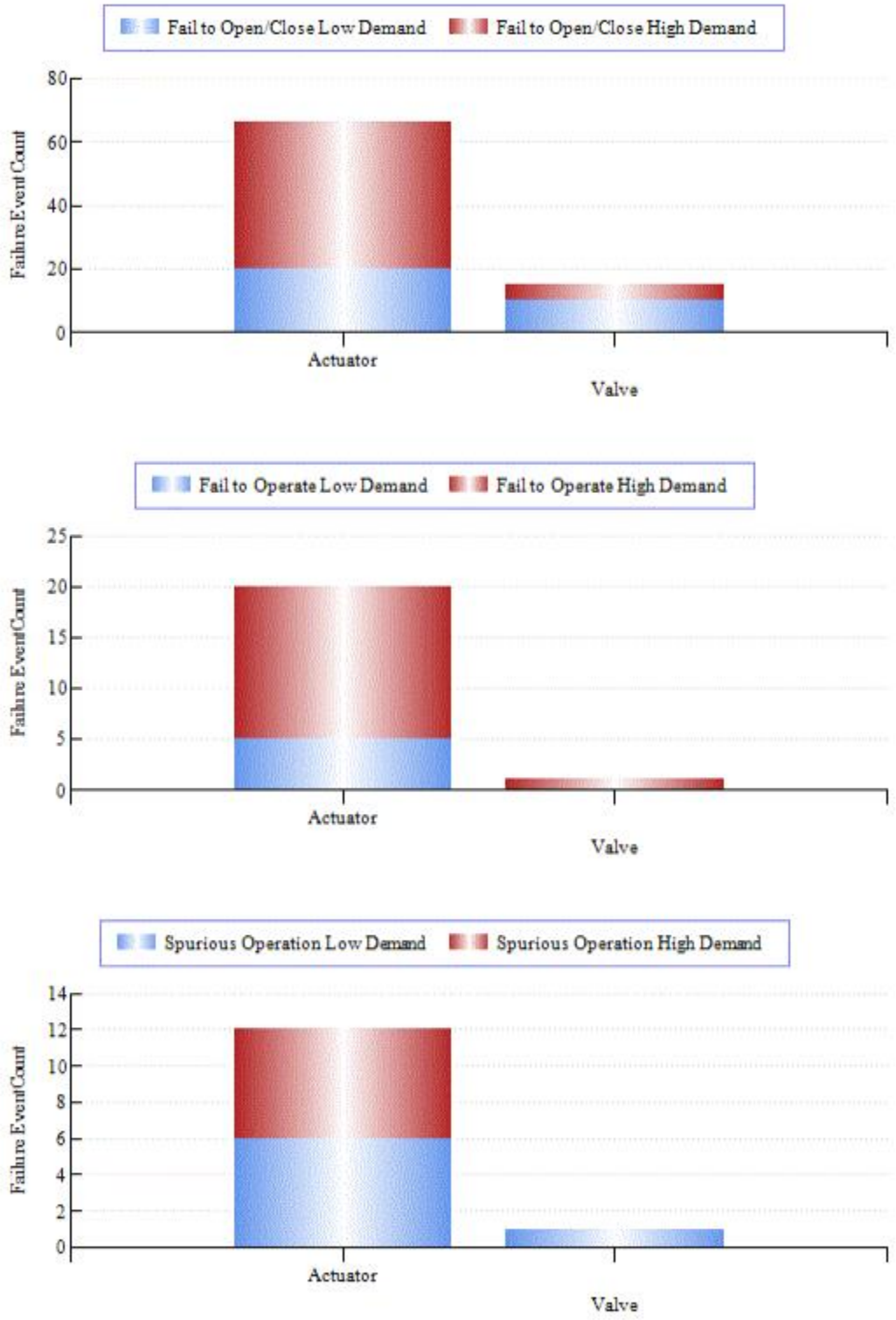

Figure 15. AOV failure event breakdown by subcomponent, failure mode, and demand rate

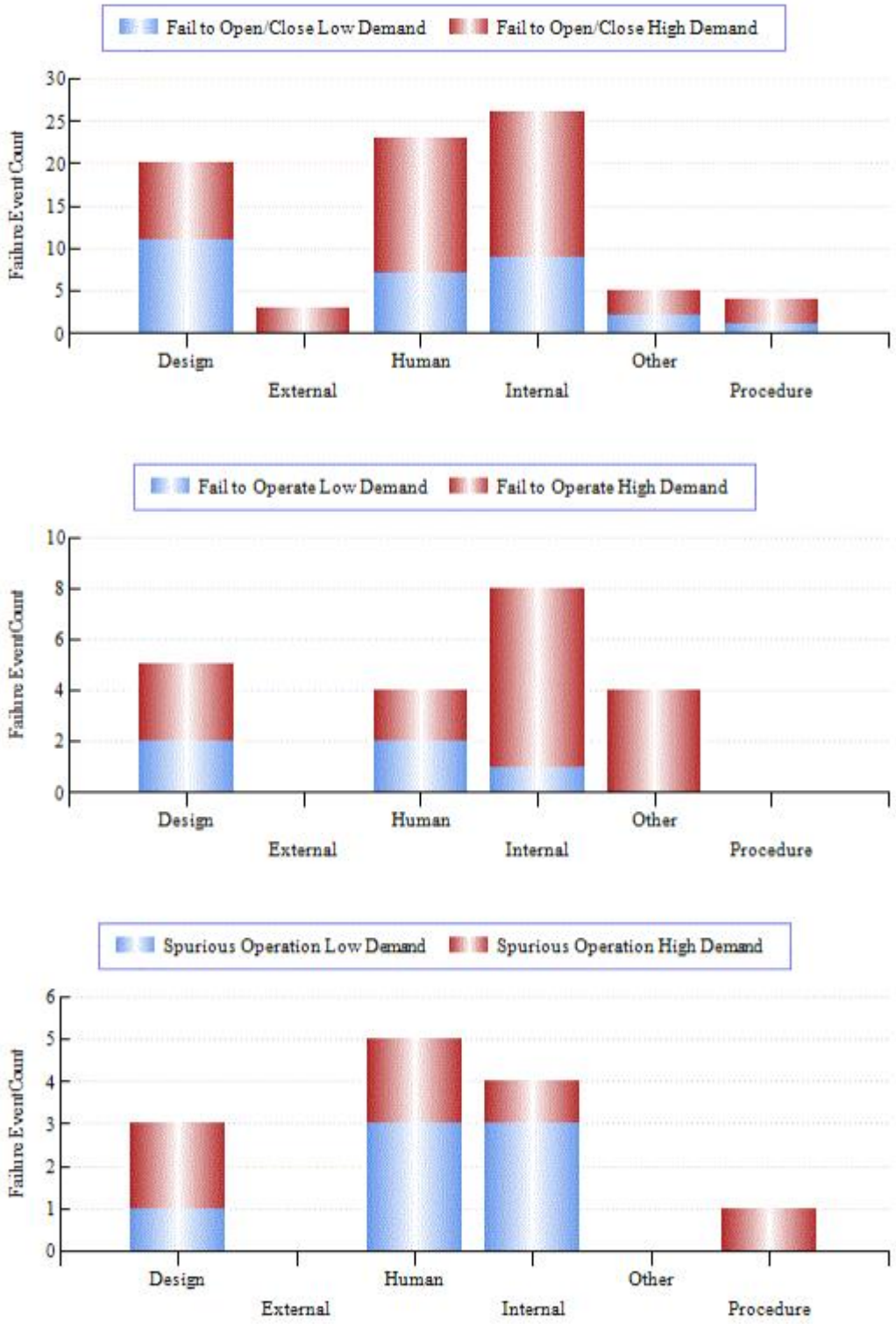

Figure 16. AOV failure event breakdown by cause group, failure mode, and demand rate

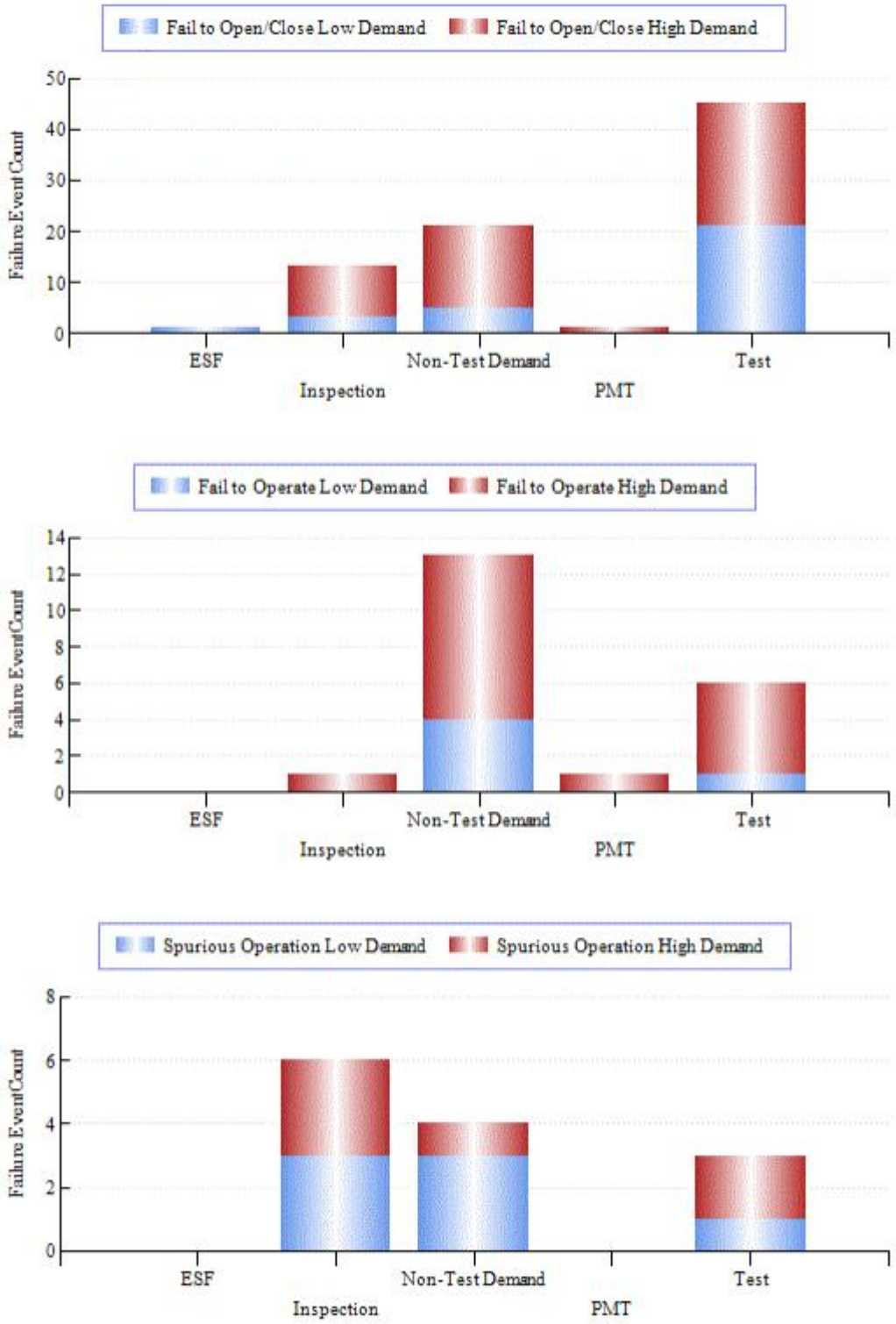

Figure 17. AOV failure event breakdown by method of detection, failure mode, and demand rate

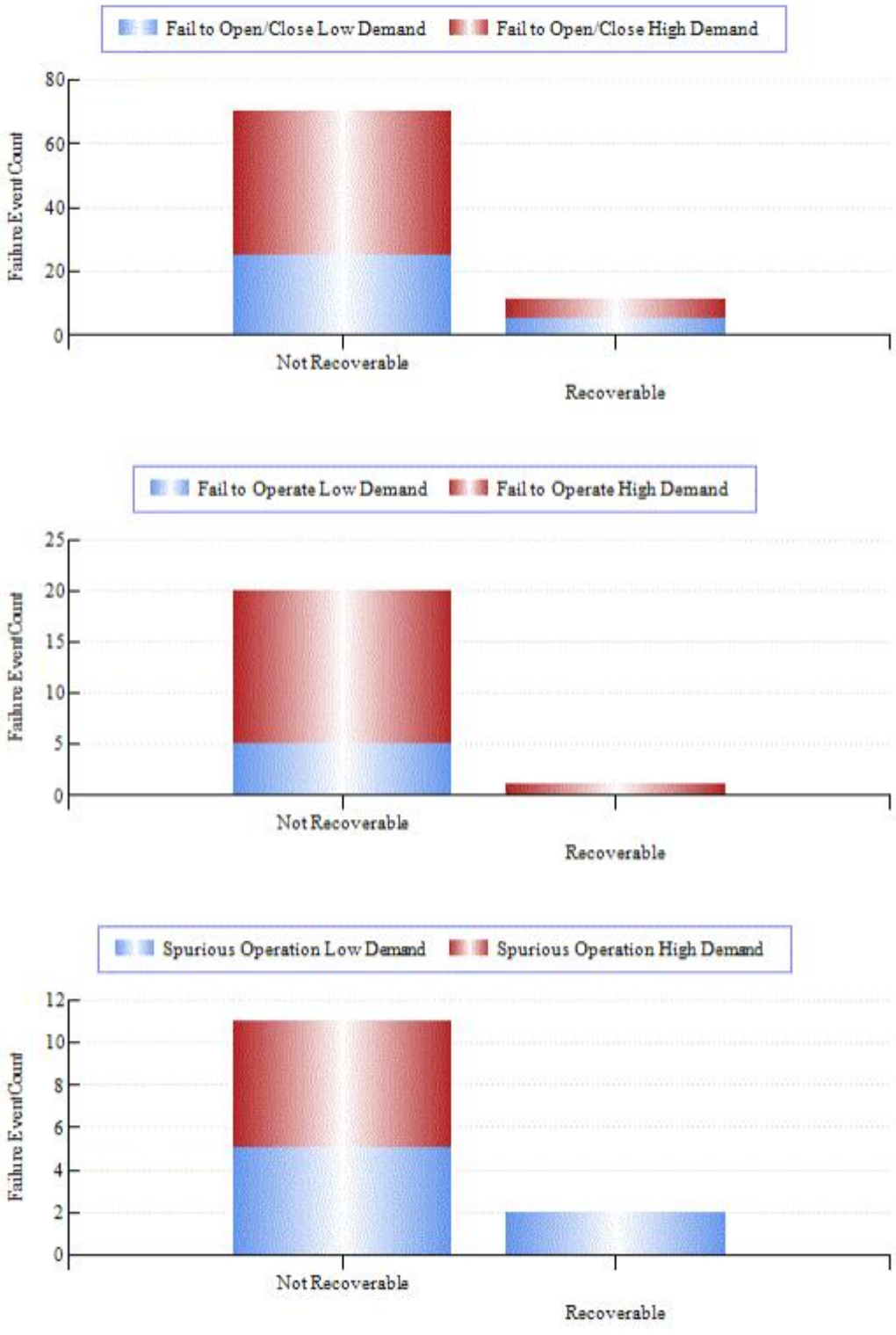

Figure 18. AOV failure event breakdown by recoverability, failure mode, and demand rate

5. AOV ASSEMBLY DESCRIPTION

An AOV assembly consists of a valve body and pneumatic operator sub-components. The valve body is generally a globe or butterfly type. The pneumatic operator is generally a piston or diaphragm type actuator. Main steam isolation valves and power operated relief valves are excluded from the AOV study even though pneumatically operated, as these are valves with different design and operating features.

The piece-parts of the valve body are the stem, packing, and internals. The pneumatic operator piece-parts may include piston internals/seals or diaphragm, positioner, mechanical linkage, volume booster, pilot valve, bolting, air regulator, airline, and wiring/contacts. Failures associated with instrument air systems that are not integral to the AOV assembly (e.g., contamination from the instrument air system that failed the AOV) are excluded in the AOV analysis.

Failure modes for the AOV include

- FTOC, which combines the fail to open and fail to close failure modes into a single category;
- FTOP, which is a rate-based failure mode that includes fail to control for a flow/temperature control device and any other rate-based failure modes except for SO, and
- SO, which includes spurious opening and spurious closing.

6. DATA TABLES

Table 10. Plot data for Figure 1, failure probability estimate trend for all systems, industry-wide, low-demand AOV FTOC.

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	Failures	Demands	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
2015 Update						3.89E-05	2.27E-03	7.56E-04
1998	9	8,275				5.58E-04	1.80E-03	1.05E-03
1999	6	8,787				3.07E-04	1.30E-03	6.78E-04
2000	5	8,124				2.56E-04	1.25E-03	6.16E-04
2001	8	8,296				4.77E-04	1.66E-03	9.35E-04
2002	4	8,580				1.77E-04	1.05E-03	4.80E-04
2003	6	8,590				3.14E-04	1.33E-03	6.92E-04
2004	3	8,264				1.20E-04	9.33E-04	3.86E-04
2005	4	8,188				1.85E-04	1.09E-03	5.01E-04
2006	10	7,836				6.71E-04	2.04E-03	1.22E-03
2007	6	7,714	7.81E-04	4.01E-04	1.52E-03	3.46E-04	1.47E-03	7.64E-04
2008	4	7,768	7.21E-04	4.11E-04	1.26E-03	1.94E-04	1.15E-03	5.25E-04
2009	5	7,874	6.66E-04	4.15E-04	1.07E-03	2.64E-04	1.29E-03	6.34E-04
2010	5	7,741	6.15E-04	4.07E-04	9.27E-04	2.68E-04	1.31E-03	6.44E-04
2011	10	7,839	5.67E-04	3.83E-04	8.40E-04	6.71E-04	2.04E-03	1.22E-03
2012	2	7,847	5.24E-04	3.44E-04	7.98E-04	6.62E-05	8.13E-04	2.89E-04
2013	8	7,774	4.84E-04	2.97E-04	7.88E-04	5.06E-04	1.76E-03	9.91E-04
2014	3	7,657	4.47E-04	2.50E-04	7.98E-04	1.28E-04	1.00E-03	4.14E-04
2015	4	7,767	4.12E-04	2.07E-04	8.21E-04	1.94E-04	1.15E-03	5.25E-04
2016	1	7,546	3.81E-04	1.70E-04	8.53E-04	2.11E-05	6.63E-04	1.80E-04
Total	103	152,467						

Table 11. Plot data for Figure 2, failure probability estimate trend for all systems, industry-wide, high-demand AOV FTOC.

			Regression Curve Data Points			Plot Trend Error Bar Points		
Year	Failures	Demands	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
2015 Update						3.89E-05	2.27E-03	7.56E-04
1998	15	27,309				3.28E-04	8.05E-04	5.27E-04
1999	8	28,098				1.43E-04	4.99E-04	2.81E-04
2000	11	27,456				2.21E-04	6.36E-04	3.89E-04
2001	5	27,342				7.76E-05	3.79E-04	1.87E-04
2002	6	27,116				1.01E-04	4.27E-04	2.22E-04
2003	9	27,560				1.70E-04	5.50E-04	3.20E-04
2004	10	26,926				2.00E-04	6.05E-04	3.61E-04
2005	6	26,893				1.02E-04	4.31E-04	2.24E-04
2006	6	27,317				1.00E-04	4.25E-04	2.21E-04
2007	2	27,340	1.85E-04	8.37E-05	4.08E-04	1.94E-05	2.39E-04	8.49E-05
2008	9	27,205	1.90E-04	9.69E-05	3.73E-04	1.73E-04	5.57E-04	3.24E-04
2009	4	26,592	1.96E-04	1.11E-04	3.45E-04	5.79E-05	3.43E-04	1.57E-04
2010	11	26,632	2.01E-04	1.25E-04	3.25E-04	2.28E-04	6.55E-04	4.00E-04
2011	6	26,450	2.07E-04	1.35E-04	3.17E-04	1.03E-04	4.37E-04	2.28E-04
2012	3	26,299	2.13E-04	1.41E-04	3.23E-04	3.81E-05	2.98E-04	1.23E-04
2013	8	26,099	2.19E-04	1.39E-04	3.45E-04	1.54E-04	5.34E-04	3.01E-04
2014	10	26,133	2.26E-04	1.33E-04	3.83E-04	2.05E-04	6.22E-04	3.72E-04
2015	4	26,152	2.32E-04	1.24E-04	4.36E-04	5.88E-05	3.48E-04	1.59E-04
2016	5	26,060	2.39E-04	1.13E-04	5.03E-04	8.12E-05	3.97E-04	1.95E-04
Total	138	510,979						

Table 12. Plot data for Figure 3, failure rate estimate trend for all systems, industry-wide, low-demand AOV FTOP.

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	Failures	Hours	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
2015 Update						2.39E-08	6.03E-07	2.27E-07
1998	0	9,977,640				1.33E-10	2.64E-07	3.38E-08
1999	3	9,942,600				7.34E-08	5.73E-07	2.37E-07
2000	3	10,047,720				7.29E-08	5.69E-07	2.35E-07
2001	1	10,047,720				1.18E-08	3.72E-07	1.01E-07
2002	1	10,047,720				1.18E-08	3.72E-07	1.01E-07
2003	1	10,065,240				1.18E-08	3.72E-07	1.01E-07
2004	0	10,065,240				1.32E-10	2.63E-07	3.36E-08
2005	2	10,065,240				3.85E-08	4.73E-07	1.68E-07
2006	0	10,179,120				1.31E-10	2.61E-07	3.33E-08
2007	2	10,082,760	6.65E-08	2.33E-08	1.90E-07	3.84E-08	4.72E-07	1.68E-07
2008	0	10,091,520	6.98E-08	2.87E-08	1.70E-07	1.32E-10	2.62E-07	3.35E-08
2009	1	10,074,000	7.33E-08	3.47E-08	1.55E-07	1.18E-08	3.72E-07	1.01E-07
2010	0	10,074,000	7.70E-08	4.08E-08	1.45E-07	1.32E-10	2.62E-07	3.36E-08
2011	1	10,231,680	8.08E-08	4.58E-08	1.43E-07	1.17E-08	3.68E-07	9.97E-08
2012	0	10,135,320	8.48E-08	4.84E-08	1.49E-07	1.31E-10	2.61E-07	3.34E-08
2013	3	10,152,840	8.90E-08	4.80E-08	1.65E-07	7.24E-08	5.65E-07	2.34E-07
2014	1	10,135,320	9.35E-08	4.54E-08	1.93E-07	1.18E-08	3.70E-07	1.00E-07
2015	1	10,126,560	9.81E-08	4.15E-08	2.32E-07	1.18E-08	3.70E-07	1.00E-07
2016	1	10,091,520	1.03E-07	3.73E-08	2.84E-07	1.18E-08	3.71E-07	1.01E-07
Total	21	191,633,760						

Table 13. Plot data for Figure 4, failure rate estimate trend for all systems, industry-wide, high-demand AOV FTOP.

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	Failures	Hours	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
2015 Update						2.39E-08	6.03E-07	2.27E-07
1998	3	8,286,960				1.14E-07	8.88E-07	3.68E-07
1999	4	8,278,200				1.75E-07	1.03E-06	4.73E-07
2000	8	8,295,720				4.55E-07	1.58E-06	8.92E-07
2001	1	8,234,400				1.86E-08	5.85E-07	1.58E-07
2002	1	8,216,880				1.86E-08	5.86E-07	1.59E-07
2003	5	8,234,400				2.42E-07	1.18E-06	5.81E-07
2004	3	8,216,880				1.15E-07	8.95E-07	3.70E-07
2005	3	8,208,120				1.15E-07	8.96E-07	3.71E-07
2006	0	8,199,360				2.08E-10	4.14E-07	5.30E-08
2007	2	8,190,600	3.66E-07	2.49E-07	5.39E-07	6.08E-08	7.46E-07	2.65E-07
2008	4	8,199,360	3.71E-07	2.67E-07	5.15E-07	1.76E-07	1.04E-06	4.77E-07
2009	3	8,076,720	3.76E-07	2.85E-07	4.95E-07	1.16E-07	9.08E-07	3.76E-07
2010	3	8,076,720	3.81E-07	3.01E-07	4.82E-07	1.16E-07	9.08E-07	3.76E-07
2011	3	8,094,240	3.86E-07	3.13E-07	4.76E-07	1.16E-07	9.07E-07	3.75E-07
2012	4	7,980,360	3.91E-07	3.17E-07	4.82E-07	1.80E-07	1.07E-06	4.88E-07
2013	3	7,962,840	3.96E-07	3.15E-07	5.00E-07	1.18E-07	9.20E-07	3.81E-07
2014	3	7,901,520	4.02E-07	3.06E-07	5.27E-07	1.19E-07	9.26E-07	3.83E-07
2015	5	7,901,520	4.07E-07	2.95E-07	5.62E-07	2.50E-07	1.22E-06	6.02E-07
2016	2	7,901,520	4.13E-07	2.82E-07	6.04E-07	6.27E-08	7.70E-07	2.74E-07
Total	60	154,456,320						

Table 14. Plot data for Figure 5, failure rate estimate trend for all systems, industry-wide, low-demand AOV SO.

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	Failures	Hours	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
2015 Update						5.76E-09	3.01E-07	1.02E-07
1998	0	9,977,640				1.46E-10	2.90E-07	3.71E-08
1999	7	9,942,600				2.70E-07	1.03E-06	5.58E-07
2000	4	10,047,720				1.23E-07	7.27E-07	3.32E-07
2001	2	10,047,720				4.23E-08	5.20E-07	1.85E-07
2002	7	10,047,720				2.68E-07	1.02E-06	5.54E-07
2003	2	10,065,240				4.23E-08	5.19E-07	1.84E-07
2004	1	10,065,240				1.30E-08	4.08E-07	1.11E-07
2005	0	10,065,240				1.45E-10	2.88E-07	3.69E-08
2006	1	10,179,120				1.29E-08	4.05E-07	1.10E-07
2007	1	10,082,760	1.67E-07	6.58E-08	4.22E-07	1.30E-08	4.08E-07	1.11E-07
2008	2	10,091,520	1.53E-07	7.00E-08	3.36E-07	4.22E-08	5.18E-07	1.84E-07
2009	1	10,074,000	1.41E-07	7.30E-08	2.74E-07	1.30E-08	4.08E-07	1.11E-07
2010	1	10,074,000	1.30E-07	7.37E-08	2.30E-07	1.30E-08	4.08E-07	1.11E-07
2011	2	10,231,680	1.20E-07	7.10E-08	2.02E-07	4.17E-08	5.13E-07	1.82E-07
2012	4	10,135,320	1.10E-07	6.43E-08	1.89E-07	1.22E-07	7.22E-07	3.30E-07
2013	1	10,152,840	1.02E-07	5.50E-08	1.87E-07	1.29E-08	4.06E-07	1.10E-07
2014	0	10,135,320	9.35E-08	4.53E-08	1.93E-07	1.44E-10	2.87E-07	3.67E-08
2015	2	10,126,560	8.61E-08	3.64E-08	2.04E-07	4.21E-08	5.17E-07	1.84E-07
2016	0	10,091,520	7.93E-08	2.89E-08	2.18E-07	1.45E-10	2.88E-07	3.68E-08
Total	38	191,633,760						

Table 15. Plot data for Figure 6, failure rate estimate trend for all systems, industry-wide, high-demand AOV SO.

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	Failures	Hours	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
2015 Update						5.76E-09	3.01E-07	1.02E-07
1998	2	8,286,960				4.40E-08	5.41E-07	1.92E-07
1999	2	8,278,200				4.41E-08	5.41E-07	1.92E-07
2000	0	8,295,720				1.51E-10	3.00E-07	3.84E-08
2001	3	8,234,400				8.36E-08	6.53E-07	2.70E-07
2002	1	8,216,880				1.36E-08	4.28E-07	1.16E-07
2003	0	8,234,400				1.52E-10	3.02E-07	3.86E-08
2004	1	8,216,880				1.36E-08	4.28E-07	1.16E-07
2005	0	8,208,120				1.52E-10	3.02E-07	3.87E-08
2006	1	8,199,360				1.36E-08	4.28E-07	1.16E-07
2007	0	8,190,600	9.93E-08	3.15E-08	3.14E-07	1.52E-10	3.03E-07	3.87E-08
2008	1	8,199,360	9.44E-08	3.56E-08	2.50E-07	1.36E-08	4.28E-07	1.16E-07
2009	2	8,076,720	8.98E-08	3.95E-08	2.04E-07	4.47E-08	5.50E-07	1.95E-07
2010	2	8,076,720	8.54E-08	4.24E-08	1.72E-07	4.47E-08	5.50E-07	1.95E-07
2011	0	8,094,240	8.11E-08	4.31E-08	1.53E-07	1.53E-10	3.05E-07	3.90E-08
2012	2	7,980,360	7.71E-08	4.08E-08	1.46E-07	4.51E-08	5.54E-07	1.97E-07
2013	0	7,962,840	7.33E-08	3.60E-08	1.49E-07	1.55E-10	3.08E-07	3.94E-08
2014	0	7,901,520	6.97E-08	3.02E-08	1.61E-07	1.56E-10	3.10E-07	3.96E-08
2015	0	7,901,520	6.63E-08	2.46E-08	1.79E-07	1.56E-10	3.10E-07	3.96E-08
2016	1	7,901,520	6.30E-08	1.96E-08	2.03E-07	1.39E-08	4.38E-07	1.19E-07
Total	18	154,456,320						

Table 16. Plot data for Figure 7, frequency (demands per reactor year) of low-demand AOV FTOC demands.

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	Demands	Reactor Years	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	8,275	87.0				9.34E+01	9.68E+01	9.51E+01
1999	8,787	87.0				9.92E+01	1.03E+02	1.01E+02
2000	8,124	87.2				9.14E+01	9.48E+01	9.31E+01
2001	8,296	87.0				9.36E+01	9.71E+01	9.54E+01
2002	8,580	87.0				9.69E+01	1.00E+02	9.86E+01
2003	8,590	87.0				9.70E+01	1.01E+02	9.87E+01
2004	8,264	87.2				9.30E+01	9.65E+01	9.47E+01
2005	8,188	87.0				9.24E+01	9.58E+01	9.41E+01
2006	7,836	87.0				8.84E+01	9.18E+01	9.01E+01
2007	7,714	87.0	8.84E+01	8.69E+01	9.00E+01	8.70E+01	9.03E+01	8.87E+01
2008	7,768	87.2	8.90E+01	8.77E+01	9.03E+01	8.74E+01	9.07E+01	8.90E+01
2009	7,874	87.0	8.95E+01	8.84E+01	9.06E+01	8.88E+01	9.22E+01	9.05E+01
2010	7,741	87.0	9.00E+01	8.91E+01	9.09E+01	8.73E+01	9.07E+01	8.90E+01
2011	7,839	87.0	9.05E+01	8.97E+01	9.14E+01	8.84E+01	9.18E+01	9.01E+01
2012	7,847	87.2	9.11E+01	9.02E+01	9.19E+01	8.83E+01	9.16E+01	8.99E+01
2013	7,774	84.6	9.16E+01	9.06E+01	9.26E+01	9.02E+01	9.37E+01	9.19E+01
2014	7,657	83.0	9.21E+01	9.10E+01	9.33E+01	9.05E+01	9.40E+01	9.23E+01
2015	7,767	82.0	9.27E+01	9.13E+01	9.40E+01	9.30E+01	9.65E+01	9.47E+01
2016	7,546	82.0	9.32E+01	9.16E+01	9.48E+01	9.03E+01	9.38E+01	9.21E+01
Total	152,467	1,637.5						

Table 17. Plot data for Figure 8, frequency (demands per reactor year) of high-demand AOV FTOC demands.

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	Demands	Reactor Years	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	27,309	103.0				2.63E+02	2.68E+02	2.65E+02
1999	28,098	103.0				2.70E+02	2.75E+02	2.73E+02
2000	27,456	103.3				2.63E+02	2.68E+02	2.66E+02
2001	27,342	103.0				2.63E+02	2.68E+02	2.65E+02
2002	27,116	103.0				2.61E+02	2.66E+02	2.63E+02
2003	27,560	103.0				2.65E+02	2.70E+02	2.68E+02
2004	26,926	103.3				2.58E+02	2.63E+02	2.61E+02
2005	26,893	103.0				2.58E+02	2.64E+02	2.61E+02
2006	27,317	103.0				2.63E+02	2.68E+02	2.65E+02
2007	27,340	103.6	2.58E+02	2.51E+02	2.64E+02	2.61E+02	2.67E+02	2.64E+02
2008	27,205	104.3	2.58E+02	2.52E+02	2.64E+02	2.58E+02	2.63E+02	2.61E+02
2009	26,592	104.0	2.58E+02	2.53E+02	2.63E+02	2.53E+02	2.58E+02	2.56E+02
2010	26,632	104.0	2.58E+02	2.54E+02	2.62E+02	2.54E+02	2.59E+02	2.56E+02
2011	26,450	104.0	2.59E+02	2.55E+02	2.62E+02	2.52E+02	2.57E+02	2.54E+02
2012	26,299	104.3	2.59E+02	2.55E+02	2.63E+02	2.50E+02	2.55E+02	2.52E+02
2013	26,099	101.6	2.59E+02	2.55E+02	2.63E+02	2.54E+02	2.60E+02	2.57E+02
2014	26,133	100.0	2.59E+02	2.55E+02	2.64E+02	2.59E+02	2.64E+02	2.61E+02
2015	26,152	99.0	2.60E+02	2.54E+02	2.65E+02	2.61E+02	2.67E+02	2.64E+02
2016	26,060	99.0	2.60E+02	2.53E+02	2.67E+02	2.61E+02	2.66E+02	2.63E+02
Total	510,979	1,951.3						

Table 18. Plot data for Figure 9, frequency (failures per reactor year) of low-demand AOV FTOC events.

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	Failures	Reactor Years	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	9	87.0				5.28E-02	1.71E-01	9.92E-02
1999	6	87.0				3.08E-02	1.30E-01	6.78E-02
2000	5	87.2				2.38E-02	1.16E-01	5.73E-02
2001	8	87.0				4.53E-02	1.57E-01	8.87E-02
2002	4	87.0				1.74E-02	1.03E-01	4.70E-02
2003	6	87.0				3.08E-02	1.30E-01	6.78E-02
2004	3	87.2				1.13E-02	8.81E-02	3.64E-02
2005	4	87.0				1.74E-02	1.03E-01	4.70E-02
2006	10	87.0				6.05E-02	1.84E-01	1.10E-01
2007	6	87.0	6.97E-02	3.53E-02	1.37E-01	3.08E-02	1.30E-01	6.78E-02
2008	4	87.2	6.45E-02	3.64E-02	1.14E-01	1.73E-02	1.02E-01	4.69E-02
2009	5	87.0	5.98E-02	3.70E-02	9.67E-02	2.39E-02	1.17E-01	5.74E-02
2010	5	87.0	5.54E-02	3.65E-02	8.41E-02	2.39E-02	1.17E-01	5.74E-02
2011	10	87.0	5.13E-02	3.46E-02	7.62E-02	6.05E-02	1.84E-01	1.10E-01
2012	2	87.2	4.76E-02	3.12E-02	7.25E-02	5.96E-03	7.32E-02	2.60E-02
2013	8	84.6	4.41E-02	2.71E-02	7.17E-02	4.64E-02	1.61E-01	9.10E-02
2014	3	83.0	4.08E-02	2.29E-02	7.29E-02	1.18E-02	9.21E-02	3.81E-02
2015	4	82.0	3.78E-02	1.90E-02	7.53E-02	1.83E-02	1.08E-01	4.96E-02
2016	1	82.0	3.50E-02	1.56E-02	7.85E-02	1.94E-03	6.10E-02	1.65E-02
Total	103	1,637.5						

Table 19. Plot data for Figure 10, frequency (failures per reactor year) of high-demand AOV FTOC events.

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	Failures	Reactor Years	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	15	103.0				8.67E-02	2.13E-01	1.39E-01
1999	8	103.0				3.90E-02	1.36E-01	7.64E-02
2000	11	103.3				5.87E-02	1.69E-01	1.03E-01
2001	5	103.0				2.06E-02	1.01E-01	4.95E-02
2002	6	103.0				2.65E-02	1.12E-01	5.85E-02
2003	9	103.0				4.55E-02	1.47E-01	8.54E-02
2004	10	103.3				5.20E-02	1.58E-01	9.42E-02
2005	6	103.0				2.65E-02	1.12E-01	5.85E-02
2006	6	103.0				2.65E-02	1.12E-01	5.85E-02
2007	2	103.6	4.76E-02	2.17E-02	1.04E-01	5.12E-03	6.29E-02	2.24E-02
2008	9	104.3	4.90E-02	2.51E-02	9.56E-02	4.50E-02	1.45E-01	8.45E-02
2009	4	104.0	5.05E-02	2.88E-02	8.86E-02	1.48E-02	8.77E-02	4.01E-02
2010	11	104.0	5.20E-02	3.23E-02	8.37E-02	5.83E-02	1.68E-01	1.03E-01
2011	6	104.0	5.36E-02	3.51E-02	8.18E-02	2.63E-02	1.11E-01	5.79E-02
2012	3	104.3	5.52E-02	3.65E-02	8.36E-02	9.63E-03	7.52E-02	3.11E-02
2013	8	101.6	5.69E-02	3.61E-02	8.97E-02	3.95E-02	1.37E-01	7.74E-02
2014	10	100.0	5.87E-02	3.45E-02	9.98E-02	5.36E-02	1.63E-01	9.71E-02
2015	4	99.0	6.04E-02	3.21E-02	1.14E-01	1.55E-02	9.18E-02	4.20E-02
2016	5	99.0	6.23E-02	2.95E-02	1.31E-01	2.13E-02	1.04E-01	5.13E-02
Total	138	1,951.3						

Table 20. Plot data for Figure 11, frequency (failures per reactor year) of low-demand AOV FTOP events.

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	Failures	Reactor Years	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	0	87.0				1.54E-05	3.06E-02	3.92E-03
1999	3	87.0				8.49E-03	6.63E-02	2.74E-02
2000	3	87.2				8.47E-03	6.61E-02	2.74E-02
2001	1	87.0				1.38E-03	4.34E-02	1.17E-02
2002	1	87.0				1.38E-03	4.34E-02	1.17E-02
2003	1	87.0				1.38E-03	4.34E-02	1.17E-02
2004	0	87.2				1.54E-05	3.05E-02	3.91E-03
2005	2	87.0				4.49E-03	5.51E-02	1.96E-02
2006	0	87.0				1.54E-05	3.06E-02	3.92E-03
2007	2	87.0	7.68E-03	2.67E-03	2.21E-02	4.49E-03	5.51E-02	1.96E-02
2008	0	87.2	8.11E-03	3.31E-03	1.99E-02	1.54E-05	3.05E-02	3.91E-03
2009	1	87.0	8.56E-03	4.02E-03	1.82E-02	1.38E-03	4.34E-02	1.17E-02
2010	0	87.0	9.04E-03	4.76E-03	1.71E-02	1.54E-05	3.06E-02	3.92E-03
2011	1	87.0	9.54E-03	5.38E-03	1.69E-02	1.38E-03	4.34E-02	1.17E-02
2012	0	87.2	1.01E-02	5.72E-03	1.77E-02	1.54E-05	3.05E-02	3.91E-03
2013	3	84.6	1.06E-02	5.70E-03	1.98E-02	8.65E-03	6.75E-02	2.79E-02
2014	1	83.0	1.12E-02	5.41E-03	2.33E-02	1.42E-03	4.48E-02	1.21E-02
2015	1	82.0	1.18E-02	4.97E-03	2.82E-02	1.43E-03	4.51E-02	1.22E-02
2016	1	82.0	1.25E-02	4.49E-03	3.49E-02	1.43E-03	4.51E-02	1.22E-02
Total	21	1,637.5						

Table 21. Plot data for Figure 12, frequency (failures per reactor year) of high-demand AOV FTOP events.

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	Failures	Reactor Years	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	3	103.0				9.13E-03	7.12E-02	2.95E-02
1999	4	103.0				1.40E-02	8.28E-02	3.79E-02
2000	8	103.3				3.64E-02	1.27E-01	7.14E-02
2001	1	103.0				1.48E-03	4.66E-02	1.26E-02
2002	1	103.0				1.48E-03	4.66E-02	1.26E-02
2003	5	103.0				1.93E-02	9.42E-02	4.63E-02
2004	3	103.3				9.10E-03	7.11E-02	2.94E-02
2005	3	103.0				9.13E-03	7.12E-02	2.95E-02
2006	0	103.0				1.66E-05	3.29E-02	4.21E-03
2007	2	103.6	2.85E-02	1.95E-02	4.18E-02	4.80E-03	5.89E-02	2.09E-02
2008	4	104.3	2.90E-02	2.09E-02	4.00E-02	1.39E-02	8.20E-02	3.75E-02
2009	3	104.0	2.94E-02	2.24E-02	3.86E-02	9.05E-03	7.06E-02	2.92E-02
2010	3	104.0	2.98E-02	2.37E-02	3.76E-02	9.05E-03	7.06E-02	2.92E-02
2011	3	104.0	3.03E-02	2.46E-02	3.72E-02	9.05E-03	7.06E-02	2.92E-02
2012	4	104.3	3.07E-02	2.50E-02	3.77E-02	1.38E-02	8.20E-02	3.75E-02
2013	3	101.6	3.12E-02	2.48E-02	3.92E-02	9.24E-03	7.21E-02	2.98E-02
2014	3	100.0	3.16E-02	2.42E-02	4.14E-02	9.36E-03	7.31E-02	3.02E-02
2015	5	99.0	3.21E-02	2.34E-02	4.42E-02	1.99E-02	9.74E-02	4.79E-02
2016	2	99.0	3.26E-02	2.24E-02	4.75E-02	4.99E-03	6.13E-02	2.18E-02
Total	60	1,951.3						

Table 22. Plot data for Figure 13, frequency (failures per reactor year) of low-demand AOV SO events.

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	Failures	Reactor Years	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	0	87.0				1.69E-05	3.36E-02	4.29E-03
1999	7	87.0				3.12E-02	1.18E-01	6.44E-02
2000	4	87.2				1.42E-02	8.43E-02	3.86E-02
2001	2	87.0				4.92E-03	6.04E-02	2.15E-02
2002	7	87.0				3.12E-02	1.18E-01	6.44E-02
2003	2	87.0				4.92E-03	6.04E-02	2.15E-02
2004	1	87.2				1.51E-03	4.74E-02	1.29E-02
2005	0	87.0				1.69E-05	3.36E-02	4.29E-03
2006	1	87.0				1.51E-03	4.75E-02	1.29E-02
2007	1	87.0	1.92E-02	7.65E-03	4.84E-02	1.51E-03	4.75E-02	1.29E-02
2008	2	87.2	1.78E-02	8.17E-03	3.89E-02	4.91E-03	6.03E-02	2.14E-02
2009	1	87.0	1.65E-02	8.57E-03	3.18E-02	1.51E-03	4.75E-02	1.29E-02
2010	1	87.0	1.53E-02	8.70E-03	2.69E-02	1.51E-03	4.75E-02	1.29E-02
2011	2	87.0	1.42E-02	8.42E-03	2.38E-02	4.92E-03	6.04E-02	2.15E-02
2012	4	87.2	1.31E-02	7.67E-03	2.25E-02	1.42E-02	8.43E-02	3.86E-02
2013	1	84.6	1.22E-02	6.61E-03	2.24E-02	1.54E-03	4.85E-02	1.32E-02
2014	0	83.0	1.13E-02	5.48E-03	2.32E-02	1.75E-05	3.47E-02	4.45E-03
2015	2	82.0	1.04E-02	4.43E-03	2.46E-02	5.14E-03	6.31E-02	2.24E-02
2016	0	82.0	9.67E-03	3.54E-03	2.64E-02	1.76E-05	3.51E-02	4.49E-03
Total	38	1,637.5						

Table 23. Plot data for Figure 14, frequency (failures per reactor year) of high-demand AOV SO events.

			Regression Curve Data Points			Yearly Estimate Data Points		
Year	Failures	Reactor Years	Mean	Lower (5%)	Upper (95%)	Lower (5%)	Upper (95%)	Mean
1998	2	103.0				3.51E-03	4.31E-02	1.53E-02
1999	2	103.0				3.51E-03	4.31E-02	1.53E-02
2000	0	103.3				1.20E-05	2.39E-02	3.06E-03
2001	3	103.0				6.64E-03	5.18E-02	2.14E-02
2002	1	103.0				1.08E-03	3.39E-02	9.19E-03
2003	0	103.0				1.20E-05	2.39E-02	3.06E-03
2004	1	103.3				1.08E-03	3.39E-02	9.17E-03
2005	0	103.0				1.20E-05	2.39E-02	3.06E-03
2006	1	103.0				1.08E-03	3.39E-02	9.19E-03
2007	0	103.6	7.77E-03	2.47E-03	2.44E-02	1.20E-05	2.38E-02	3.05E-03
2008	1	104.3	7.39E-03	2.80E-03	1.95E-02	1.07E-03	3.36E-02	9.12E-03
2009	2	104.0	7.03E-03	3.11E-03	1.59E-02	3.49E-03	4.28E-02	1.52E-02
2010	2	104.0	6.69E-03	3.34E-03	1.34E-02	3.49E-03	4.28E-02	1.52E-02
2011	0	104.0	6.36E-03	3.39E-03	1.19E-02	1.20E-05	2.38E-02	3.04E-03
2012	2	104.3	6.06E-03	3.22E-03	1.14E-02	3.48E-03	4.28E-02	1.52E-02
2013	0	101.6	5.76E-03	2.84E-03	1.17E-02	1.22E-05	2.42E-02	3.09E-03
2014	0	100.0	5.48E-03	2.39E-03	1.26E-02	1.23E-05	2.44E-02	3.12E-03
2015	0	99.0	5.22E-03	1.94E-03	1.40E-02	1.23E-05	2.45E-02	3.14E-03
2016	1	99.0	4.96E-03	1.55E-03	1.59E-02	1.10E-03	3.48E-02	9.42E-03
Total	18	1,951.3						

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